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Organic Household Waste Management in Rotterdam

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1. Introduction

At its current state, humanity consumes more than earth can produce for it. This year, Earth Overshoot Day was on the 29th of July (Earth Overshoot Day, 2019). That means that we have consumed as much natural resources by that time as the earth can renew in a whole year. Everything we consume past that date is excessive. If we continue this trend, we will need two earths by 2030 to provide for our consumption behaviour. Therefore, our economy is going to have to be based around more awareness for sustainability and circularity. The past decade a lot of attention has been given to more sustainable solutions to our environmental problems. Fossil fuels are getting replaced for greener alternatives and we are trying to find new sustainable solutions for our energy consumption. We have to become a circular economy. A big challenge facing us on the journey to become circular is waste transition. Waste management needs to be improved thoroughly when it comes to circularity.

Currently, waste is often thrown in the same bin, labelled as residual waste. In reality, however, a lot of the waste that ends up on the pile of residuals does not belong there. Our economy has been consuming in an unsustainable manner. In 2015, less than 10% of the materials flowing through our economy are being recycled (Haas, Krausmann, Wiedenhofer & Heinz, 2015). Traditionally, materials are being used to make a certain product, after which this product is used. Thereafter, those products are often thrown away. In a circular economy, waste materials are being separated in order to be recycled and be used again. This is not only a more efficient manner of using materials, it also saves a lot of money. A circular economy is an economy in which materials can be recovered and used again. The circular model builds economic, natural and social capital (The Ellen MacArthur Foundation, 2017)

At the moment, we are far away from living in a circular economy. A lot of resource cycles are still open, meaning a lot of potential resources are lost. To become circular, a lot of separate goals have to be achieved. These goals differ per country and even within countries there are different plans to obtain these goals. Since these objectives differ, we solely focus on Rotterdam in this paper. The municipality of Rotterdam has asked Metabolic to write a report for the plans of Rotterdam regarding circularity for the coming years. In this report, "Circulair Rotterdam (2018)", there are 4 sectors identified which are going to be tackled in the coming years. These are identified as 1) Agricultural food and green streams, 2) Construction sector, 3) Consumption goods and 4) health care sector.

This paper will focus solely on the agricultural food and green streams, as these are clear to identify within the city. It studies the food and waste management of Rotterdam. Currently, 14% of the food entering Rotterdam is wasted, compared to 12% nationwide (Circulair Rotterdam, 2018). Furthermore, not all waste is separated. While glass, paper and residual waste is collected separately citywide, this does not hold for organic waste. Organic waste contains a lot of chemical connections that are lost when burned together with the residual waste. Alternatively, green streams can be processed an reused as compost or gas for electricity (Circulair Rotterdam, 2018).

In Rotterdam, only a few neighbourhoods have facilities to separate their organic waste, but since 75% of the inhabitants of Rotterdam live in apartments (Circulair Rotterdam, 2018). It is difficult to do so everywhere as there is a lack of space within houses. However, the municipality is busy with plans to provide every inhabitant of Rotterdam with the facilities for separating organic waste. This paper will identify these plans and try to compare them to prior research on this topic. If waste management can be improved this could potentially save a lot of resources in the future. To identify the potential benefits of a more circular waste management and the added value of it, this paper will try to answer the following research question:

"Under which circumstances does the separation of organic waste in Rotterdam households have economic benefits?"

To answer this question, the findings of prior research will be compared to the current situation in Rotterdam. The present-day amounts of total waste and separated organic waste in Rotterdam will be identified. Previous literature on this topic will give an insight of how much organic waste can be separated potentially. This will provide some different cases on how the situation can change and improve circularity. Furthermore, this will enable to calculate the potential economic benefits of organic waste collection.

First, some theoretical framework will be provided. The concept of circularity will be explained as well as the importance of waste separation for circularity, both socially and financially. Thereafter a literature review will compare some prior research on organic waste collection and its presumed benefits, including collection methods, waste processing and behavioral concepts. This helps to draw a clearer picture of plans similar to those of the *Gemeente Rotterdam* and is important for the research. Following that, the methodology of the research will be explained, based on findings from the literature review. Subsequently, a quantitative research will be conducted to calculate the potential benefits of separate collection of organic waste in Rotterdam. This research will compare the current situation in Rotterdam to 2 potential future cases, extracted from the literature review. The results will be followed by a discussion and conclusion. Finally, recommendations on future policy and research are provided.

2. <u>Literature review</u>

2.1 Circular economy

The term circularity is often confused with the term sustainability. Although there are a lot of similarities between the two, there are also differences. Geissdoerfer, Savaget, Bocken & Hultink (2017) have performed a literature review in order to detect those similarities and differences. In their paper, they describe sustainability as *"the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations."* This means that people, businesses and governments behave more consciously towards the environment by using more durable products. This can be enforced through regulations, industry transformations or by creating more awareness towards their current behaviour. The term circular economy is defined by them as *"a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."* This is in contrast with a linear economy, in which resource cycles are not closed (The Ellen MacArthur Foundation, 2017). These definitions suggest that sustainability is a condition for something to be circular, however a process does not necessarily have to be circular in order for it to be sustainable.

The current situation in Europe is far from circular (European Commission, 2019). Most resource cycles are still linear. In order to become a circular economy, it is important to find methods to close resource cycles. There are a lot of different resource cycles and thus a lot of steps to be taken to become circular. Therefore, every country has formed their own nationally determined contributions (NDCs) to reach the goals formulated in the Paris Agreement (United Nations Framework Convention on Climate Change, 2018). These NDCs are mostly divided over different sectors and are often clear goals on the reduction of CO_2 emission per sector. The circular economy is very important in order to reduce CO_2 emission as closed resource cycles do not form much added CO_2, in contrast to linear cycles (The Ellen MacArthur Foundation, 2017). Brussels has been pushing European countries to become more circular. The European Union has set goals for its member states to reuse and recycle more while decreasing their waste.

Within Europe, there are vast differences between countries regarding to which extent they are circular. In order to rank the EU countries in terms of circularity, the European

Commission has made up a set of metrics (European Commission, 2018). While countries like Denmark, Sweden and The Netherlands are one of the greenest worldwide according to the Environmental Performance Index (2019), they are not necessarily the most circular. Politico (2018) has researched the data for seven of the European Commission's key metrics to rank the 28 member states in terms of circularity. The Netherlands only ranks 12th out of 28. This is caused by the fact that environmentally friendly practices are not always circular. Economically well performing countries like Denmark, Sweden and The Netherlands produce a lot of waste and burn this waste to produce energy. This is green, but not very circular. While these countries are known to be front runners in terms of innovation and recycling, their tendency to produce a lot of garbage and food waste causes them to score low on the overall circularity ranking.

Therefore it is very important for a country like the Netherlands to improve their waste management. Only then it will be able to reach its goals and become one of the most circular countries worldwide. The European Union has set goals for its member states. In the same way, the Dutch government has set goals for its regions and municipalities to become more circular. The responsibility of reaching the goals in the Netherlands have been regionalized. Local governments are relatively free to decide in which manner they want to reach these goals, as long as they do so. It is not easy nor costless to transit from a waste collection system to a more circular alternative. Therefore it is important to introduce an effective new policy. Fortunately, prior research on waste collection have taken place in other Western and Asian cities. These can prove valuable for a policymaker. For this reason, a literature review of prior research in the field of organic waste collection methods is necessary in order to write a satisfactory recommendation for an effective new waste policy.

2.2 Waste management

Waste management is not an easy subject for policymakers. In order to change household behaviour with respect to waste, a lot of different factors that affect whether or not a new waste policy will be a success have to be taken into account. If not all parties concerned are participating effectively this can cause a policy to be inefficient and costly. In regard to household waste management the involved parties consist of the government, municipalities and households itself. Policymakers face different factors affecting these parties' behaviour. In this literature review, these different factors will be studied from researches in Western and Asian countries. Firstly, information concerning waste policy is very important for all involved parties. This will be explained in the first section. Secondly, the importance of facilities for separating household waste is discussed. Thereafter, waste pricing strategies will be handled. Finally, a conclusion will be drawn, which will lead to recommendations for new waste policies that will enforce a change in waste behaviour.

2.2.1 Information

In this section, the importance of information on waste management for households' waste behaviour will be explained. Policymakers can decide on new waste policies, however it is important that the participating households are well informed about waste management. This varies from information on how to separate different waste streams correctly to reasoning as to why a new policy has been introduced. According to Stern (1999), information and incentives have different functions and when correctly deployed they can have a synergistic effect on proenvironmental behaviour. Nonetheless, there are many other personal and contextual factors that interact and can be a barrier to behaviour change despite correct information and incentives. Even so the fact remains that proper information is inherent to behaviour change.

Zaman & Lehmann (2011) identify that one of the barriers to proenvironmental behaviour in Western countries is that consumers are not aware of the fact that waste is a precious resource. If consumers knew the value of food waste, glass and packaging cardboard for instance, they would not label this as residual waste as easy. This is in line with findings by Parizeau, von Massow & Martin (2015), who conclude that "*education and skill-building could prove* *useful"* to those who believe that Canadian individuals who do not know how to reduce household waste are responsible. They add to this that food waste is not necessarily an environmental or economic issue, but just as much a social issue. Their results suggest that "*social messaging in educational and promotional materials to reduce household waste"* is therefore important.

Lehman (2011) also suggests that at first, waste creation could be prevented by maximizing the value of resources by recovering them through promoting cyclical reuse of material. This is harmonious with results from Ghani, Rusli, Biak & Idris (2013), whose survey showed that Malaysians have a positive attitude towards recycling and waste separation as long as they are informed about the benefits it has for them as an individual. They showed that people who are informed about the positive outcomes of source separation are more willing to participate in recycling and waste separation programs.

However, the literature suggests that waste management cannot be improved when improving education and skills on the topic alone. Stern (1999) states that there are a vast number of other factors that can form a barrier to change a certain behavioral choice. This is similar to what Parizeau, von Massow & Martin (2015) find. They believe that the relationship between behaviour, attitudes, beliefs and waste generation rates lies deeper than just an informative barrier. Their survey data suggests that there are households who are committed to source separation of waste in their homes, but face constraints like opportunity costs and time. This means that end-of-the-pipe solutions alone are not enough to change behaviour. For example, the influence of municipal household waste collection systems on the waste behaviour of individuals should be taken into consideration as well. Furthermore, Stern (1999) suggests that convenience is one of the most important limiting factors regarding proenvironmental behaviour. Therefore it is important to look broader than information alone, which leads to another factor influencing behaviour: facilities for waste management.

2.2.2 Facilities

The survey employed in the research by Ghani, Rusli, Biak & Idris (2013) showed that if the Malaysian public is well informed and as a result has a positive attitude towards source separation of food waste, they are more willing to participate in such programs, given that the situational factors such as storage convenience and collection times are facilitated. This suggests that facilities are an important factor in changing households' food waste separation behaviour. The responsibility for facilitating the situational factors usually lies with the local government. Local policymakers decide what policies for waste management are applied to their city. Households rely on the waste management system supplied to them and their waste behaviour is affected by the provided facilities.

Stoeva & Alrikkson (2017) performed a study with university students from Sweden and Bulgaria aimed to find out how recycling programs in both countries influenced the inhabitants' participation in separation of household waste. Their research showed that the waste separation behaviour of individuals is reliant on the provided facilities. The respondents from both groups had a positive attitude towards waste separation, nevertheless it was showed that a lack of proper situational factors prevented individuals to take part in the process of waste separation. However, when the local conditions for waste separation were satisfactory, the respondents' behaviour depended on their *"personal attitudes towards waste separation and recycling."* This outlines that individuals' behaviour is not only dependent on personal attitudes, but also on provided facilities.

Similar results were obtained from a case-study by Bernstad (2014) in a residential area in Malmö, Sweden. The study consisted of two strategies aimed at increasing household source separation of food waste. The first group of households was provided with leaflets with written information on food waste separation, while the second group of households were provided with an installation of source separation equipment in their household in order to increase convenience of sorting food waste. The results depicted that the distribution of written information leaflets had no significant increased effect on either the amount of separately collected food waste nor the source-separation ratio. On the other hand, after the installation of waste sorting equipment within the households both the amount of separately collected food waste as the source-separation ratio had increased significantly. This 44% increase in source-separation ratio remained consistent, even months after the implementation. These results prove that situational factors such as convenience, accessibility and infrastructure are important to increase participation rates in household waste recycling. In this case the separation equipment was installed within the kitchens of households. This improved the convenience of waste separation and influenced the behaviour of households.

A similar research was conducted by Rispo, Williams & Shaw (2015) in a deprived urban area in London, UK. The respondents' were from a high-rise, high-density neighborhood. In contrast to the previous researches the participants in this research consisted mainly of poor households. For this reason, the amount of food waste per household was much lower than average. Nevertheless, the results resembled the outcomes from other pilots, as the participation rate in this neighborhood was influenced by the available facilities. The participants of the recycling program had similar attitudes towards waste separation as their peers who did not participate. When convenience increased and facilities were provided for, however, the amount of collected food waste in the participating neighborhood increased. While the authors acknowledge that an introduction of such a waste management system in deprived areas might not prove to be cost-effective in the short term, this research provides useful information on the effect of facilities on waste behaviour of households. There are a lot of factors influencing the waste behaviour of households. Just as information regarding the topic has proven to be useful, facilities are inherent to waste behaviour change.

However, it is difficult for policymakers to assess which waste management system is preferred, as many factors have proven to be an influencing factor to household waste behaviour. Gellynck, Jacobsen & Verhelst (2011) have tried to identify different factors that influence the amount of residual household waste in the Flemish part of Belgium. In their research they performed a pilot in which the waste management system was altered. Firstly, they increased the costs for residual waste collection. As a result, the total volume of residual household waste per capita decreased. Thereafter, they lowered the frequency of residual household waste collection as well as introducing curbside collection of organic waste. This led to a decrease in residual household waste per capita and an increase in total amount of organic waste collected. This was no surprise, as organic waste makes up about 40% of total waste in this part of Belgium. Interesting, however, is that by decreasing the convenience of residual waste collection through pricing the amount of residual household waste per capita decreased. This insight leads to another factor influencing the waste behaviour of households, which is the pricing of residual household waste. If incentives of individuals can be influenced by pricing their residual waste behaviour, this can prove to be very useful for policymakers. Therefore it is an important factor to be involved in the waste management policymakers' toolkit.

2.2.3 Pricing

If information and facilities cannot perfectly predict household waste behaviour it means that other factors play a role, too. Incentives with respect to waste behaviour can be influenced by charging people for their waste. Waste disposal can be seen as a good with elasticity. Pricing certain types of waste can affect peoples' decision making with respect to waste. Fullerton and Kinnaman (1996) for instance, proved that a unit-based pricing system (UPS) can be effective when charging households for their residual waste. In this case, households from Charlottesville were charged with a fee per bag of residual waste. The introduction of this UPS caused a significant 14% weight decrease of total waste. The volume of total waste decreased by 37%. This implies that the weight per bag increased, as people tend to scram more waste in a bag when charged per bag. Another negative effect of this UPS was that more illegal dumping of waste took place after the introduction of the UPS. Trying to prevent this illegal dumping is difficult as well as expensive. Nevertheless, since the total weight of waste decreased the wished effects were achieved. Furthermore, the weight of recyclable waste increased with 16% as an effect of the UPS. Thus in this case, pay-as-you-throw rates proved effective for reducing residual waste as well as increasing the recycling rate among residents.

This is in line with the findings by Hong (1999), who examined the waste behaviour of various Korean communities after the introduction of a volume-based UPS accompanied by aggressive recycling programs. After implementation, the amount of total residual waste decreased by 17.8%. Moreover, recycling rates increased by 26.8%. It is difficult to assess whether this effect was caused by either the introduction of the UPS or the recycling program alone. Nonetheless, the waste behaviour of households was influenced and changed. When the author studied price incentives of waste separately, however, the effects of the UPS were limited. An increase in price tends to decrease the households' demand for residual waste collection, as the quantity of source-separated recyclables increases. In spite of that, the fee effect is partially offset by a decrease in source-reduction efforts because of the feedback effects. This shows that in this case non-recyclables have a low-price elasticity. Authorities may want to raise pay-as-you-throw fees, but this will not reduce the households' demand for solid waste collection by much. However, when solid waste fees are accompanied by further recycling incentives such as more frequent pick up of recyclables and more recycling options, its demand will decrease.

Besides volume based UPS's, there are also weight based pricing systems. Linderhof, Kooreman, Allers & Wiersma (2001) studied the effects of a weight-based pricing system in the municipality of Oostzaan, the Netherlands. Three years after the introduction of this weight-based UPS, the annual total waste collection had dropped by 42%. This was partially caused by a 56% decrease of residual waste. Furthermore, the amount of recyclable waste increased substantially, as this could be dropped free of charge. In this research, a weight-based pricing system proved to be cost effective as well as achieving the wished effects on households' waste behaviour. However, one should note that these effects were found in Oostzaan, a small municipality. There are hardly any high-rise buildings, making curbside collection possible. Furthermore, social pressure in such a community is much higher, as people are hardly anonymous. This is in contrast with large cities with many high-rise buildings, were the consequences of unwished behaviour are much smaller as it is harder to prevent.

These results are harmonious with findings by Hong (1999), who proved that weight-based pricing systems are more effective than volume-based UPS's, as in the latter case people tend to compact their solid waste, increasing the weight per bag. However, weight-based pricing systems are very expensive to implement and a cost-benefit analysis on a real world setting is impossible, as cities and neighbourhoods differ too much for one system to be perfect. To add to this, volume-based pricing systems have proven to be effective as well, as various researches showed that it decreased the total amount of residual waste. Additionally, volume-based pricing systems are much easier to implement. Any negative externalities following the implementation of an UPS, such as illegal dumping, apply to both systems. The most cost-effective system is therefore a volume-based UPS.

2.2.4 Conclusion

Following the literature review we can conclude that there is no policy which can affect households' waste behaviour perfectly. Nonetheless, there are a lot of factors influencing behaviour in a positive manner. Firstly, different researches showed that by providing information, the incentives of households are changed positively. Lack of knowledge on waste causes people to act in an unwishful manner. By providing households with information on waste and its potential benefits, proenvironmental behaviour is stimulated. Secondly it was proven that information alone does not satisfactory influence households' waste behaviour. Individuals with a proenvironmental state of mind will still act in an unsustainable manner when not provide with the right facilities. In order to promote recycling behaviour, information should be accompanied by recycling facilities. This includes frequent collection and high convenience of recyclable waste. By making recyclable waste more convenient to offer, people are willing to do so. Also, by decreasing the convenience of residual waste collection the amounts of residual waste tend to decrease. Another inconvenience of residual waste collection studied was the introduction of an unit pricing system. Several researches proved that a pay-as-you-throw fee of waste has a decreasing effect on the total amount of residual waste. When accompanied by recycling programs it also increased the amount of food waste collection. It is not always proven to be cost-effective, however. Nevertheless should policymakers take an UPS in mind. To conclude, the literature review shows that an effective waste policy consists of both information and facilities. In order to improve recycling rates even more, a policymaker could also introduce a pay-as-you-throw fee for residual waste.

2.2.5 The Rotterdam case

According to the report Circulair Rotterdam (2018), currently only about 22% of the solid waste in Rotterdam is being recycled. This number could potentially be much higher. However, the goal of Rotterdam is not only to become a "zero waste" city. One of the main objectives is to create more awareness across the city. This awareness must be spread amongst the 4 sectors mentioned in the introduction. This research will focus on the agri-food and green streams, the sector which is most tangible for regular citizens. This leads to the Rotterdam case of organic household waste management. The *Gemeente Rotterdam* wants to improve the recycling behaviour of its citizens, especially with respect to organic waste. The current situation is far from circular and therefore a new waste management policy is needed. Following the studied literature, 3 cases will be introduced. The first case will be the base and represents the current situation. It contains the present day amounts of residual and organic waste. The second case is an estimate of a new situation in which all citizens of Rotterdam are provided with both information and facilities for organic waste. The amount of additional recycled organic waste will be subtracted from the base number of residual waste and added to the new number of organic waste. The third case will be similar to the second case, as another new situation is introduced. Next to the effect of information and facilities, the additional effect of a volume based pay-as-you-throw pricing system will be calculated. This will give an overview of the estimated effects of the different policy options the *Gemeente Rotterdam* faces.

3. <u>Methodology and Data</u>

Rotterdam is not the best performing city regarding waste management. Only about 6% of all organic waste in Rotterdam is separated (Circulair Rotterdam, 2018). This means that about 94% of the organic waste ends up on the pile of residual waste and is processed in a manner that is inefficient and unsustainable. To give an impression: Rotterdam produces 82,300 tons of household organic waste on a yearly basis. Thus, only 4,938 tons of this organic waste is processed correctly. In Rotterdam, organic waste makes up 40.1% of the total amount of household waste in the city (Gemeente Rotterdam, 2018). This results in a total of 205,237 tons of total household waste on a yearly basis. That is the current situation and will be the first case.

3.1 The cases

This research will measure the impact of new waste policies on the amount of household residual and organic waste and its economic benefits. By using results from the review literature, potential effects of new policies on the recycling rates of organic waste can be predicted. By using these predictions, an estimation of the potential economic benefits of new waste management policies are made. In order to make a considered prediction, the cases will consist of a conservative and a progressive estimate. These will be based on results from the literature review.

In this research, economic benefits will be expressed in two ways. First, saved costs from processing organic waste in a correct manner instead of burning it together with residual waste will be expressed as an economic benefit. The processing costs of organic waste are much lower compared to the costs of processing residual waste. In a serious recycling program this leads to costs savings which can be seen as an economic benefit. Secondly, by processing organic waste correctly, CO_2 that would have otherwise ended up in the atmosphere will be conserved. That conserved CO_2 will be the second economic benefit. CO_2 can be expressed in value, however this will not be done in this paper as it is disputable whether this saved CO_2 will really yield the *Gemeente* this benefits in terms of money. Both economic benefits will be expressed on a yearly basis.

The first case will be the current situation. An estimation of current costs and saved CO_2 will give a base situation. Thereafter, the *facility case* will be introduced. This will be the effect of a waste management policy in which people are provided with information and facilities for organic waste separation. The literature review suggests that this will lead to an increased recycling rate and thus more organic waste can be processed correctly. Following that, the *pricing case* will be introduced in which not only the effect of facilities and information, but also the additional effect of a volume based unit pricing system will be introduced. Pricing has an effect on waste behaviour and is therefore important to include as a separate factor in this third case.

3.2 Data

The data used for this research will come from different sources. The household waste figures of Rotterdam will come from data provided by the *Gemeente Rotterdam*. This includes the amount of total household waste, organic household waste and the current proportion of organic household waste in the city. The costs of processing residual household waste and organic waste are taken from estimates by *Rijkswaterstaat*, who keeps track of waste processing costs. The potential CO_2 that is saved as a result of processing a ton of organic waste correctly is calculated with the model provided by *Vereniging Afvalbedrijven.* The amount of citizens and the prognosed increase of citizens is based on data obtained from *Buurtmonitor.*

3.3 Assumptions

During this research, a few assumptions are made in order to make estimates on the potential economic benefits of separating organic household waste in Rotterdam.

- Total household waste in Rotterdam in 2019 is 205,237 tons of waste. Every year, this value increases with population growth. Assumptions of the effect of population growth on waste creation are taken from the paper by Dyson & Chang (2005), who found that waste in a city increases as population does

- Population growth will be based on the estimates by *Buurtmonitor*, who predict that the population will grow on average by 3870 people per year in the period 2020-2030. The current population of Rotterdam is 644,337 (Buurtmonitor, 2019).

- Total household waste = total residual household waste + total organic household waste

- Costs of processing a ton of residual household waste = €69
- Costs of processing a ton of organic household waste = €23
- Amount of CO_2 saved per ton of correctly processed organic household waste = 202kg CO_2/ton of organic waste
- Conservative increase of organic waste recycle rate due to information and facilities = 8%
- Progressive increase of organic waste recycle rate due to information and facilities = 44%
- Conservative increase of organic waste recycle rate after volume based UPS = 16%
- Progressive increase of organic waste recycle rate after volume based UPS = 26.8%
- It is assumed that the population and amount of waste in the city of Rotterdam will not change over the course of the next 10 years.

See the appendix for explanations regarding these assumptions.

By using these assumptions, an estimation of the potential economic benefits in the 3 cases can be made and easily be compared. The cases will make use of a few formulas in order to make these estimations.

3.4 Formulas

- $Total\ household\ waste = total\ residual\ household\ waste + total\ organic\ household\ waste$

This means that total household waste is the sum of total residual household waste and total organic household waste. In this case, residual household waste is defined as all types of waste excluding organic waste.

- $Total\ household\ waste\ year\ x = total\ household\ waste\ year\ x - 1 * population\ growth\ rate$

Total household waste changes every year, due to population growth. The total household waste of year x-1 is multiplied by the population growth which gives a new total.

- $New\ total\ organic\ household\ waste = old\ total\ organic\ household\ waste * increased\ recycling\ rate$

Total organic household waste from the basic case is multiplied by the increase in recycling rate obtained from the literature review. This gives a new value to total organic household waste.

- $New\ total\ residual\ household\ waste = Old\ total\ residual\ household\ waste - difference\ in\ organic\ household\ waste$

The increase in organic household waste is subtracted from the amount of prior residual household waste, resulting in a new total of residual household waste.

- $Total\ waste\ processing\ costs = (total\ residual\ household\ waste\ in\ tons * €69) + (total\ organic\ household\ waste\ in\ tons * €23)$

The total costs of processing waste is calculated by taking the total amount of residual household waste in tons and multiplying it by its processing costs and adding the amount of total organic household waste multiplied by the corresponding processing costs, resulting in the total waste processing costs.

- $Total\ amount\ of\ saved\ CO2 = difference\ in\ organic\ household\ waste\ in\ tons * 202kg$

Per ton of organic waste that did not end up with the residual waste, 202kg of CO_2 is saved. The increase in organic household waste in tons is multiplied by 202kg, resulting in the total number of saved CO_2.

4. Results

Year	Inhabitants	Total household waste in tons	Residual waste in tons	Organic waste	Processing costs	CO_2 Saved
2019	644,337	205,237	200299	4,938	€ 13,934,199	997
2020	648,207	206,470	201502	4,968	€ 14,017,896	1,003
2021	652,077	207,702	202705	4,997	€ 14,101,587	1,009
2022	655,947	208,935	203908	5,027	€ 14,185,279	1,015
2023	659,817	210,168	205111	5,057	€ 14,268,970	1,021
2024	663,687	211,400	206314	5,086	€ 14,352,661	1,027
2025	667,557	212,633	207517	5,116	€ 14,436,352	1,033
2026	671,427	213,866	208720	5,146	€ 14,520,044	1,039
2027	675,297	215,099	209923	5,175	€ 14,603,735	1,045
2028	679,167	216,331	211126	5,205	€ 14,687,426	1,051
2029	683,037	217,564	212329	5,235	€ 14,771,117	1,057
Total	-	-	-	-	€ 157,879,266	11,302

Fig. 1: Amount of waste streams and costs in the basic case. Waste figures and CO_2 are expressed in tons.

4.1 The Basic Case

The current situation in Rotterdam is clear. Of the 82,300 tons of organic waste per year, only 4,938 tons (6%) are processed in a circular manner (*Appendix).* That means that in 2019 77,362 tons of organic waste in Rotterdam could potentially be processed more circular. However this is not the case and therefore this waste is burned together with the rest of the residual waste. This leads to a situation in which total processing costs of household waste in 2019 in Rotterdam result in more than €13,9 million. Furthermore, only 997 tons of CO_2 are saved in 2019, while this number could potentially be much higher relatively. Due to the increasing population, the amount of waste will increase as well. If no new policy is introduced, we can assume that recycling rates will stay the same. This results in even more processing costs over the next 10 years. In 2029, total processing costs are estimated to be more than €14,7 million. Over a 10 year period, this leads to total waste processing costs of €157,9 million and 11,302 tons of CO_2 saved. The reason that there are no relative cost or CO_2 savings is due to the fact that it is estimated that waste behaviour of people will not change much when no new policy is introduced.

4.2 The Facility Case

The Facility Case will be an estimate of the effect of providing information and facilities for organic waste separation in households. There are 2 predictions, which are a conservative and a progressive one. The cost reductions and amounts of conserved CO_2 are calculated to give an insight of the impact of such a recycling program.

4.2.1 Conservative facility case

Year	Processing costs	Tons of CO_2 Saved
2019	€ 13,631,335	2,327
2020	€ 13,713,213	2,341
2021	€ 13,795,085	2,355
2022	€ 13,876,957	2,369
2023	€ 13,958,830	2,383
2024	€ 14,040,702	2,397
2025	€ 14,122,574	2,411
2026	€ 14,204,446	2,425
2027	€ 14,286,318	2,439
2028	€ 14,368,191	2,453
2029	€ 14,450,063	2,467
Total	€ 154,447,713	26,371

Fig. 2.1: Waste processing costs and tons of CO_2 conserved in the conservative facility case.

The conservative case predicts that recycling rates for organic waste go up by 8%, thus that 8% more of total organic waste is recycled. This means that now 14% of all organic household waste in Rotterdam would be separated, which results in a total of 11,522 tons of recycled organics in 2019. The impact of that increase would lead to a yearly waste processing cost reduction of more than €300,000 as compared to the base situation. Furthermore, an extra 1,330 tons of CO_2 is conserved in 2019, resulting in a total of 2,327 tons. Over the period 2019-2029, total processing costs sum up to €154,4 million euros, which is above €3,2 million less compared to the basic case. Furthermore, 26,371 tons of CO_2 are saved over a 10 year period, which is 15,069 tons more compared to the basic case.

4.2.2 Progressive facility case

Year	Processing costs	Tons of CO_2 saved
2019	€ 12,268,447	8,312
2020	€ 12,342,139	8,362
2021	€ 12,415,825	8,412
2022	€ 12,489,511	8,462
2023	€ 12,563,198	8,512
2024	€ 12,636,884	8,562
2025	€ 12,710,571	8,612
2026	€ 12,784,257	8,662
2027	€ 12,857,944	8,712
2028	€ 12,931,630	8,762
2029	€ 13,005,317	8,812
Total	€ 139,005,723	94,181

Fig. 2.2: Waste processing costs and tons of CO_2 conserved in the progressive facility case.

In the progressive facility case it is estimated that due to information and facilities recycling rates increase with 44%, resulting in a total recycling rate of 50%. This would lead to a total of 41,150 tons of recycled organic household waste in 2019. This increase would mean that in this case total yearly waste processing costs are reduced by €1,6 million in 2019. Furthermore, compared to the base situation an additional 7,315 tons of CO_2 would be conserved in that year. On a 10 year basis, providing facilities and information for organic waste separation could lead to more than €18,8 million in cost reductions as well as more than 82,800 tons of extra conserved CO_2 in the progressive facility case as compared to the basic case.

4.3 The Pricing Case

The Pricing Case contains an estimation of the effect of applying a pay-as-you-throw rate per bag of residual waste, additional to providing information and facilities for separating organic waste. The effects of this policy will be studied in a conservative and a progressive case to give a more clear insight of the additional effect of pricing residual waste by the bag.

4.3.1 Conservative pricing case

Year	Processing costs	Tons of CO_2 saved
2019	€ 13,025.607	4,987
2020	€ 13,103,847	5,017
2021	€ 13,182,081	5,047
2022	€ 13,260,315	5,077
2023	€ 13,338,549	5,107
2024	€ 13,416,783	5,137
2025	€ 13,495,017	5,167
2026	€ 13,573,251	5,197
2027	€ 13,651,485	5,227
2028	€ 13,729,719	5,257
2029	€ 13,807,953	5,287
Total	€ 147,584,606	56,509

Fig 3.1: Processing costs and tons of CO_2 conserved in the conservative pricing case.

In the conservative pricing case, a volume-based UPS could lead to an additional 16% increase in recycling rate. This leads to a total of 30% separation rate of organic household waste, totaling to a 24,690 tons of recycled organic household waste in 2019. This prediction would lead to a decrease of more than €900,000 of waste processing costs in 2019. Additionally, in 2019 an extra 3,990 tons of CO_2 is conserved in this progressive estimation. Considering the increase in total household waste combined with the increased recycling rate, on a 10 year basis this would mean the *Gemeente Rotterdam* could save almost €10,3 million on waste processing costs as well as saving and additional 45,207 tons of CO_2.

4.3.2 Progressive pricing case

Year	Processing costs	Tons of CO_2 saved
2019	€ 11,253,852	12,768
2020	€ 11,321,450	12,844
2021	€ 11,389,043	12,921
2022	€ 11,456,635	12,998
2023	€ 11,524,228	13,074
2024	€ 11,591,820	13,151
2025	€ 11,659,413	13,228
2026	€ 11,727,006	13,304
2027	€ 11,794,598	13,381
2028	€ 11,862,191	13,458
2029	€ 11,929,783	13,535
Total	€ 127,510,019	144,662

Fig 3.2: Processing costs and tons of CO_2 conserved in the progressive pricing case.

The progressive pricing case predicts that a pay-as-you-throw rate per bag leads to an additional 26,8% of organic waste being recycled. That totals the separation rate of organic household waste to 76,8%. In this case, 63,206 tons of organic household waste would be separated from the residual household waste in 2019, which would save around €2,6 million in processing costs. Furthermore, an additional 11,771 tons of CO_2 would be saved in 2019 which results in a total of 12,768 tons of conserved CO_2. When looking at a period of 10 years, this increased recycling rate could save the *Gemeente Rotterdam* a total of more than €30,0 million as well as conserving more than an extra 133,300 tons of CO_2 compared to the basic situation.

5. Conclusion

5.1 Discussion

The results predict that new waste policies could potentially save the *Gemeente Rotterdam* processing costs as well cutting in their household waste CO_2 emission. It is certain that a lot of organic waste could be recycled in a more circular manner. Both facilities as an additional fee per bag of residual household waste have the potential to create a more circular cycle with respect to household waste.

As for the facility cases, the range of the conservative and progressive case could potentially lead to processing cost savings between €3,3 million and €18,8 million on a 10 year basis. Furthermore, between 15,000 and 82,800 tons of CO_2 could be saved in this period. Considering that the conservative case is estimated on numbers found in one of the poorest neighborhoods in London, the number is possibly higher than the conservative case. The progressive case is based on figures from flat buildings in Malmö, thus on small scale and from a sample that not represents all classes. It can be assumed that facilities will not be such a success in the whole city of Rotterdam as it was in Malmö. Nevertheless, providing facilities could lead to a lot of cost and CO_2 savings.

For additional unit pricing per bag cases, the range between the conservative and progressive case estimates household waste processing cost savings to vary between €10,0 million and €30,0 million. Moreover, between 45,00 and 133,300 tons of CO_2 extra could be conserved. Of course, with multiple assumptions on the success of implementation this number could vary and most probably will not be as high as the progressive case. This case is based on numbers from Malmö as well as Korean living communities which were strictly monitored. When comparing this to Rotterdam, it will be improbable that it will be such a success on large scale.

In the results, however, no implementation costs have been taken into account. In reality this does not hold. If the *Gemeente Rotterdam* decides to implement a new waste policy, this will bring additional costs. At the moment, there are hardly any facilities for separating organic household waste at all. For both cases, it is necessary that the *Gemeente* provides underground bins for organic waste throughout the city. Furthermore, people will have to be provided with small organic waste bins for their kitchen. Also, garbage trucks are needed to drive more often as there are different types of waste bins to be emptied. This causes additional costs as well as CO_2 emission. To add to this, both cases are based on the assumption that people will always perfectly separate their waste streams, while in reality people make mistakes and this brings additional sorting costs with it. However, the cost and CO_2 savings provide an additional budget to implement a new recycling system, which could be cost beneficial in the long term.

Another downside to the volume based unit pricing system is that it increases the amount of illegal dumping of garbage bags (Fullerton & Kinnaman, 1996). People who are charged a pay-as-you-throw fee per bag are more inclined to throw a bag somewhere in the bushes, for example. Firstly, this will lead to additional cleaning costs as the *Gemeente* has to provide extra workers to clean this mess. Secondly, a lot of litter on the streets does not improve the image of the city of Rotterdam. A clean city can be more valuable, both for tourism reasons as to the citizens itself. This certainly has to be taken in mind when deciding on a policy.

5.2 Recommendations

The *Gemeente Rotterdam* has to decide on a new waste policy for organic household waste. Following the results, there are a lot of options to improve the circularity of its household waste management. The range of both cases is large and thus there are a lot of uncertainties which make it difficult to decide on a perfect policy. Nevertheless, the information is still useful. As a policymaker it could be wise to choose for a new system in which people are provided with information and facilities for separating organic household waste. In the past it has proven to be successful and it is relatively easy to implement on a large scale. The additional pay-as-you-throw fee per bag is based on too much uncertainties. It is harder to monitor, as citizens in Rotterdam live relatively anonymous. This causes social pressure to be lower than in the papers studied in the literature review. For this reason, it is hard to predict whether the extra costs attached to it weigh up to the benefits. Facilities, on the other hand, are relatively easy to provide and it has been shown that it does increase the recycle rate in households in the past. It comes with less uncertainties and still has the potential to increase household organic waste separation quite a lot. This in combination with reverse collection of residual household waste could prove to be an effective waste policy in Rotterdam.

5.3 Limitations

This paper is built on a lot of assumptions. In reality, the assumptions will not hold. For instance, waste processing costs can change over the course of this period. The assumptions on the effectiveness of the different policies are based on the literature review. The papers studied in this review have used samples which are not representative for the whole city of Rotterdam. While the studied policies might have been effective on a small scale, it is always uncertain whether this will also be the case when applied to the whole city of Rotterdam. Furthermore, alternative effects like decreasing total waste due to a more sustainable lifestyle have not be taken into account. Nevertheless, this paper can be seen as an useful insight on household waste behaviour and possible factors which influence it. Further study is needed and as every city is different it is always difficult to write a one-fit perfect policy.

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7. <u>Appendix</u>

1: *Rijkswaterstaat states that in 2017, the average processing costs for a ton of residual household waste in the Netherlands are about €69. Adding to this, the Gemeente Rotterdam states that processing costs for a ton of organic household waste is 3 times as cheap as compared to residual household waste. This is in line with findings on the website of Rijkswaterstaat.*

2: *Using the CO_2-tool of Vereniging Afvalbedrijven it results that per ton of processed organic waste, about 202kg of CO_2 are saved. This because it is not burned with residual waste. These calculations are based on assumptions that the Gemeente Rotterdam uses thermophilic fermentation processes for composting and uses part of that warmth for heating. This fermentation leads to gases which can be used to generate electricity. Furthermore, the Gemeente Rotterdam makes uses of composting by using parts of its coffee grounds for the Rotterzwam project.*

3: *Conservative increase of organic waste recycle rate due to information and facilities is based on the results by Rispo, Williams & Shaw (2015), who provided facilities in a poor neighborhood in London, UK and found an 8% increase in organic waste recycling*

Progressive increase of organic waste recycle rate due to information and facilities is based on the results by Bernstad (2014), who provided facilities in different flat buildings in Malmö, Sweden and found an increased recycling rate of 44%

Conservative increase of organic waste recycle rate after volume based UPS is based on the results by Fullerton & Kinnaman (1996), whose results were found in Charlottesville, US and found an 16% increase in recycling.

Progressive increase of organic waste recycle rate after volume based UPS is based on the results by Hong (1999) that were found in a very effective volume based UPS in Korea which resulted in a 26,8% increased recycling rate.

__4:__ Amounts of waste streams in tons in the Facility Cases

Year	Total household waste	Conservative residual	Conservative organic	Progressive Residual	Progressive organic
2019	205,237	193,715	11,522	164,087	41,150
2020	206,470	194,878	11,591	165,073	41,397
2021	207,702	196,042	11,660	166,058	41,644
2022	208,935	197,205	11,730	167,044	41,891
2023	210,168	198,369	11,799	168,029	42,139
2024	211,400	199,532	11,868	169,015	42,386
2025	212,633	200,696	11,937	170,000	42,633
2026	213,866	201,859	12,006	170,986	42,880
2027	215,099	203,023	12,076	171,971	43,127
2028	216,331	204,186	12,145	172,957	43,374
2029	217564	205350	12214	173942	43622

__5:__ Amounts of waste streams in tons in the Pricing Cases

Year	Total household waste	Conservative residual	Conservative organic	Progressive residual	Progressive organic
2019	205,237	180,547	24,690	142,031	63,206
2020	206,470	181,631	24,838	142,884	63,586
2021	207,702	182,716	24,987	143,737	63,966
2022	208,935	183,800	25,135	144,590	64,345
2023	210,168	184,885	25,283	145,443	64,725
2024	211,400	185,969	25,431	146,296	65,105
2025	212,633	187,053	25,580	147,149	65,484
2026	213,866	188,138	25,728	148,002	65,864
2027	215,099	189,222	25,876	148,855	66,243
2028	216,331	190,307	26,025	149,708	66,623
2029	217,564	191,391	26,173	150,561	67,003